CHAPTER 5. MERV ISSUES AND METHODOLOGIES FOR FORESTRY PROJECTS

In this chapter, we briefly review the different types of forestry projects that will be subject to MERV guidelines and discuss some of the unique features of forestry projects that distinguish them from energy-efficiency and renewable energy projects. After examining two MERV issues in particular (i.e., monitoring domain and socioeconomic impacts), we describe the following methodological issues: (1) measurement perspectives; (2) methodologies for data collection, monitoring, and evaluation; (3) inventory analysis of carbon pools; and (4) net carbon impacts.

5.1. Introduction

Unlike energy efficiency and renewable energy projects, forestry projects may not only reduce emissions but may also remove carbon from the atmosphere and store it (carbon sequestration). Carbon sequestration plays an important role in reducing accumulated carbon dioxide in the atmosphere. Green plants remove (sequester) carbon from the atmosphere by way of photosynthesis, using the carbon to make biomass in the form of roots, stems, and foliage. The sequestration process ends when the carbon is released back to the atmosphere principally as carbon dioxide, through either combustion or decay processes. Carbon can also be removed from the forest as trees are harvested. Some of the carbon, however, might not return directly to the atmosphere. If the trees are used to make wood products, a portion of the carbon sequestered over the growth period will remain in solid form up to several decades. If the harvested trees are used to produce energy, carbon will be released through combustion. This could offset carbon that would have been released through the burning of fossil fuels.

5.2. Types of Projects

The forestry sector affects a broad range of potential GHG sources, emissions reductions activities, and carbon sequestration activities. There are basically three categories of forest management practices that can be employed to curb the rate of increase in carbon dioxide in the atmosphere (Brown et al. 1996). These categories are: (1) management for conservation, (2) management for storage, and (3) management for substitution.

The goal of conservation management is primarily to conserve existing carbon pools in forests as much as possible through options such as controlling deforestation, protecting forests in reserves (forest preservation), modified forest management (e.g., reduced impact logging, hardwood control, precommercial thin, commercial thin, firewood harvests, fertilization, and prescribed fire), and controlling other anthropogenic disturbances such as fire and pest outbreaks.

The goal of storage management is to expand the storage of carbon in forest ecosystems by increasing the area or carbon density of natural and plantation forests and increasing storage in durable wood products. Thus, this would include afforestation (i.e., the planting of trees in areas absent of trees in recent times), reforestation (i.e., the planting of trees where trees had recently been before, but currently are absent), urban forestry (i.e., the planting of trees in urban or suburban settings), and agroforestry (i.e., planting and managing trees in conjunction with agricultural crops).

Finally, substitution management aims at increasing the transfer of forest biomass carbon into products (e.g., construction materials and biofuels) that can replace fossil-fuel-based energy and products, cement-based products, and other building materials. This type of management would include short-rotation woody biomass energy plantations.

Forestry projects can also be classified by carbon stocks (Table 9) (Swisher 1996). This type of typology is useful because forestry projects have different carbon flows: some store carbon in standing natural forest, some accumulate carbon in new biomass grown in the project, some accumulate carbon in harvested products that enter long-term storage, and biomass energy farms and plantations store additional net carbon in unburned fossil fuel by preventing carbon emissions from fossil fuel use. The relative size of the carbon pools, and potential changes in the carbon pools from climate change mitigation projects, will determine the type of monitoring and evaluation that will be needed for a specific project. If the carbon pools are small, or if the potential changes to the carbon pool from a project are minor, then less resources will need to be developed for MERV activities.

Table 9. Forestry Projects and Parameters for Calculation of Net Carbon Storage
("+" means the carbon stock applies to the project classification; "0" means it does not)

	Carbon Stock				
Project Type	**Standing Biomass**	**New Biomass**	**Harvested Biomass**	**Soil Carbon**	**Saved Fossil Energy**
Conservation management					
Forest reserves /reduced deforestation	+	0	0	+	0
Natural forest management	+	0	+	+	0
Storage management					
Timber plantations /wood products	0	+	+	+	0
Forest/ecosystem restoration	0	+	0	+	0
Agroforestry/social forestry	+	+	+	+	0
Fuelwood farms (noncommercial)	+	+	0	+	0
Dryland restoration (annual crop)	0	0	+	+	0
Substitution management					
Biomass commercial energy farms	0	0	0	+	+
Biomass energy plantations	0	+	0	+	+

Source: Swisher (1996)

5.2.1. Biomass energy plantations

The conventional view of forest management assumes that initial forest establishment is followed by a relatively extensive period of growth (and carbon accumulation). In contrast, biomass energy plantations occupy an intermediate position between forestry and annual agriculture. With woody biomass crops, harvesting occurs approximately every 5-12 years, and regeneration is accomplished by methods that rely on regrowth of new stands from the root stock of the harvested stand (DOE 1994b). Biomass energy plantations also occupy an intermediate position between forestry and energy supply projects. Analysis of these projects will depend upon information regarding how energy would have been supplied in the absence of the project. One needs to account for emissions related to the biomass fuels and the displaced fossil fuels in the energy supply sector, and the capture of carbon in the forestry sector. The carbon capture resulting from woody biomass plantations can be analyzed in conventional forestry sector terms. At the same time, the release of carbon from the combustion of biomass fuel and the displacement of emissions from fossil fuels relates more closely to activities in the energy supply sector. The MERV of the two components of biomass projects is important because the use of biomass on a renewable basis as a substitute for fossil fuels typically yields greater GHG abatement benefits than sequestration alone (World Bank 1994a).

5.2.2. Unique features of forestry projects

Some unique features make the MERV of forestry projects challenging. First, the long gestation periods of forestry projects entail a long-term monitoring process: it takes many years for a forest to grow, and many years to track the "lifetime" of wood products (see Section 5.6.6). The long gestation periods lead to uncertainty over the sustainability of the project, and affect the timing and number of observations that may be needed for measuring the persistence of GHG emission reductions and carbon sequestration (see Section 3.6).

Second, the varied extraction of wood during the life of a project necessitates multiple monitoring approaches: some forestry projects involve the harvest of timber or pulpwood for use in wood products (see Section 5.6.6). Of the carbon that reaches wood products, some remains only for a short time (1-5 years), but a significant amount remains stored in the wood products for long periods (on the order of decades) before returning to the atmosphere (DOE 1994b). The unknown fate of some of these products adds to the uncertainty level of impact measurement. The most conservative approach is to treat carbon destined for wood products as if it is released immediately after the harvest (DOE 1994b).

Third, forestry activities can have a wide range of effects: e.g., reforestation may increase fertilizer use, which can increase nitrous oxide emissions, and fossil fuel use in harvesting and transporting timber. Finally, forestry activities may have indirect impacts on GHG emissions (e.g., urban tree planting can decrease the extent and severity of urban heat islands, potentially reducing the consumption of electricity to cool buildings, thereby reducing GHG emissions).

5.3. MERV Issues

Six key MERV issues affecting the forestry sector need to be addressed by any guidelines: (1) the duration of measurement (e.g., measure carbon flows for one week, one month, six months, one year, five years, or the lifetime of a wood product (e.g., furniture)); (2) the frequency of measurement (e.g., annually, biannually, or biennially (see Section 3.5); (3) monitoring of carbon after the carbon is harvested, particularly if wood is harvested for fuel; (4) the monitoring domain, to account for project leakage, if deemed significant; (5) the calculation of net impacts using comparison plots (see below); and (6) both direct and indirect impacts, not just carbon sequestration.

5.3.1. Monitoring domain

Extensive studies of global, regional, and national level carbon inventories have been undertaken in the last decade, but, relatively little work has been done to monitor impacts of carbon storage projects (Figueres 1996). The lack of work in this area may be due to the difficulties in addressing monitoring domain issues (see Sections 1.2.1 and 3.3.1). Questions of leakage and off-site baseline changes may determine the success or failure of forest preservation projects, but they are extremely difficult to quantify.

There are three key monitoring domain issues that need to be addressed in forestry projects. First, should the impacts of forestry projects be examined only at the area of implementation (e.g., an area where a reforestation project occurs) or at the point of use (e.g., where the wood from that forest is used for furniture)?

Second, should the impacts of forestry projects be examined only at the project area, or should it cover a wider region (the “leakage problem”)? For example, the preservation of a mature forest in one country could lead to increased harvest of timber elsewhere in the country or in another country to meet market demand. Similarly, counterproductive effects of afforestation could arise if the conversion of the agricultural land had market effects that encouraged other parties to (1) convert their forest to agricultural land, (2) avoid tree planting they might otherwise have done, or (3) harvest their existing forest stands earlier than they might otherwise have done. While some believe that market leakage is not expected to rise to a significant level compared to the effect of capturing carbon (Swisher 1996), we believe that leakage should still be addressed in the guidelines.

And third, should the impacts of forestry projects continue to be assessed when forested areas are later transformed into agriculture, grassland and range?

For forestry projects, the Land Use and Carbon Sequestration (LUCS) model, available from the World Resources Institute, is one tool that may be able to address off-site leakage (Faeth et al. 1994; MacDicken 1996). The LUCS model is a project-based computer model that tracks the changes in carbon density associated with land use changes (e.g., conversion of forested areas to agriculture) and provides estimates of the costs and benefits of such changes. Direct measurements and default assumptions are used to calculate the changes and impacts. One of the more important outputs of the model is the cost per ton of carbon sequestered. The model identifies leakages, and future work is being undertaken to modify the model so that leakages can be evaluated comprehensively and quantitatively (personal communication from Willy Makundi, Lawrence Berkeley National Laboratory, July 24, 1997).

Defining the appropriate boundaries for monitoring domains must take into account important GHG pools, fluxes and leakage, both over space and time. Different techniques (see Section 5.5) are available for assessing multiple monitoring domains in forestry projects (Andrasko 1997). At the national scale, remote sensing can be used to detect land-use and land-cover changes. At the regional scale, remote sensing can be used with ground-truthing and forest inventory techniques. And at the project level, remote sensing, ground-truthing, creation of permanent plots, forest inventory data or surveys, or allometrics from other inventories applied to a new site can be used. Currently, there are weak linkages in assessing multiple monitoring domains(Andrasko 1997). One potential solution to strengthening these linkages is the use of “nested monitoring systems” where an individual project’s monitoring domain is defined to capture the most significant GHG fluxes and where provisions are made for monitoring GHG flows outside of the project area by regional systems or national GHG inventory monitoring systems (Andrasko 1997).

Another potentially useful tool for addressing monitoring domain issues in forestry projects is the development of a “leakage index” that helps determine when leakage is likely to be an issue (Brown et al. 1997). The leakage index covers the following information: (1) the main drivers of land use change and deforestation resulting from demand for agricultural land, fuelwood and timber; (2) the market boundaries of the demand (local or export use); (3) types of projects and their components; (4) conditions under which project components become vulnerable to leakage (e.g., decreased agricultural or timber output); (5) an assessment of the project’s potential for leakage (e.g., moderate or high, and short or long term); and (6) possible mitigation strategies for avoiding leakage. Using this index, one can redesign projects or, if too costly or not feasible, carbon sequestration benefits will need to be recalculated to reflect the project’s soundness (similar to what is proposed in the energy sector — see Section 4.2). In sum, the leakage index should be helpful for systematically addressing the potential for leakage.

5.3.2. Socioeconomic impacts

The socioeconomic benefits of forestry projects have made these kinds of projects beneficial in the minds of supporters of climate change mitigation projects; however, the evaluation of socioeconomic impacts is challenging and requires different resources and expertise than those associated with the monitoring of carbon flows in forests. The socioeconomic impacts are particularly relevant for forestry projects because they are more likely to address the root causes of deforestation (Andrasko et al. 1996). The socioeconomic benefits of forestry projects are particularly important for rural and developing countries, where forestry projects can have very positive impacts for the local population (e.g., ecotourism or forest warden jobs). The sustainability of forestry projects will be improved if these kinds of impacts are accounted for and recognized (see Section 3.2.3).

5.4. Measurement Perspectives

There are two different perspectives in measuring carbon stock and flow in forests: the first perspective emphasizes the dynamics of carbon flow, while the second perspective is based on an equilibrium model of carbon storage. In the first perspective, periodic measurements of carbon stock and flow are needed because of the dynamics of carbon stock and flow in forests (MacDicken 1996). Thus, guidelines are needed to measure the net flows of carbon as accurately as is practical, accounting for all positive flows (emissions) of carbon from forests (e.g., from the combustion and decay of organic matter and the use of fossil fuels in machinery) and negative flows (capture) of carbon through photosynthesis to forests. Furthermore, every action undertaken in the management of forests causes changes in stocks of biomass and, therefore, in flows of carbon. Forestry activities also typically trigger a sequence of effects that change through time, so that the measurement of carbon flows must account for these dynamic effects (e.g., from the time a forest is established until a forest is removed by harvest or a natural disturbance).

In the second perspective, for the purpose of carbon offset analysis, the dynamics of the carbon flows over time may not need to be monitored (Swisher 1996). Only long-term (more than 20 years) average or steady-state carbon storage densities need to be analyzed. The MERV of projects would therefore be done less frequently than under the first perspective.

Because we expect carbon credit claims to be verified over short periods of time (e.g., annually) and by high quality data (e.g., field measurements), we use the first perspective as the starting point for a discussion of data collection and analysis methodologies in the forestry sector.

5.5. Data Collection and Analysis Methods

The measurement of a project's carbon fixation necessitates specialized tools and methods drawn largely from experience with forest inventories and ecological research. Monitoring and verifying carbon accumulation in forestry projects must be cost effective and accurate to known levels of precision (see Section 3.4). Monitoring systems should be built upon standard forestry approaches to biomass measurement and analysis, and apply commonly accepted principles of forest inventory, soil science and ecological surveys. Field research methods need to be adapted for use with commercial-scale inventories, at levels of precision specified by funding agencies. Specific methods and procedures should be assembled on a project-specific basis, with the types and extent of monitoring ultimately determined by the relative costs and carbon returns of each measurement type.

An alternative to an inventory approach for estimating annual flows of carbon is the use of models of the impacts of certain forestry practices on carbon flows into and out of forest carbon sinks. These models start from an estimate of a carbon stock for a specific forest type at a specific site. Then, based on information from forest practices, the models develop estimates of annual carbon flows. The models need to be corrected / calibrated with measured data periodically. Some models are already available for simple conditions and standard treatments, such as tree planting on agricultural land. More complex models are being developed and appear to be progressing rapidly (DOE 1994b). However, field measurements are generally preferred over standard tables and computer models, because site-specific field studies provide higher quality data and thus higher credibility.

Six general monitoring approaches have been proposed to monitor carbon fixed through forestry projects (based on MacDicken 1997). The first approach uses a series of highly simplified assumptions to estimate total carbon sequestration. For example, assumptions could include: the number of trees planted in either woodlots or agroforestry systems, initial stocking rates, mean annual stemwood volume increments, a biomass multiplier factor, and harvest rates. The assumptions are then inputted into a model to estimate the amount of sequestered carbon. This approach requires little time and effort, and the gross estimates (not net estimates) are probably neither accurate nor precise (MacDicken 1997). This approach is similar to the engineering analyses used in estimating energy savings without field data (see Section 4.3.1).

The second approach relies on remote sensing and ground truthing (ground-based measurements) to monitor land area changes, map vegetation types, delineate strata for sampling, and assess leakage and base case assumptions. Many existing national and international projects and programs have made use of this technology for land cover change research at a national or international level (Skole et al. 1997). The Face Foundation in the Netherlands and Winrock International have used satellite imagery for evaluating climate change mitigation projects (Face Foundation 1997; MacDicken 1996).[1] Attempts to estimate biomass from remote sensors have generally been costly and have had mixed results (MacDicken 1997). Also, very little work of this kind has been done in tropical forests, which are more diverse and spatially variable than temperate forests. To date, no one has measured carbon using remote sensing. Skole et al. (1997) have proposed an international system for monitoring land cover change which includes studies in specific locations for field validation and accuracy assessments for the large area analyses; these sites could also be useful for evaluating project impacts, if integrated with the approach described next.

The third approach is the periodic inventory of carbon in baseline and project cases, analogous to the commercial assessment of timber volume or biomass. Commercial-scale carbon inventories can be performed at virtually any level of precision desired by inventory sponsors and provide flexibility in the selection of methods, depending on the costs and benefits of monitoring. One inventory-based system that has been extensively peer reviewed and field tested was developed by the Winrock International Institute for Agricultural Development and is briefly described in Section 2.1.6. We discuss some components of this approach later in the next section.

The fourth approach is research studies that use more intensive data collection and analysis methodologies to typically test research hypotheses. Research studies can provide useful detailed monitoring estimates for determining how much carbon is sequestered by projects, but it is usually more costly than other monitoring activities (MacDicken 1997).

The fifth approach uses surveys of project field activities to see what was actually implemented in the project. This type of monitoring would provide useful data for the evaluation of carbon mitigation and sequestration projects, especially if the surveys are combined with the third approach described above.

The sixth approach is the monitoring of wood production, use, and end product data in order to develop historical and trend data for the development of accurate baselines. Also, an account needs to be made of what happens to the wood once it is felled or trees and branches die (Section 5.6.6). If dead wood is regularly collected, it should be measured and its use recorded, and this monitoring activity would provide the needed information.

[1] The Face Foundation was set up by Sep (the Dutch Electricity Generating Board) to fund projects to sequester some of the carbon dioxide emitted into the atmosphere by the burning of fossil fuels when generating electricity in the Netherlands. Face stands for Forests Absorbing Carbon dioxide Emissions.

5.6. Inventory Analysis of Carbon Pools

In forestry projects, carbon accumulates primarily in four pools: above-ground biomass, below-ground biomass, soils and the litter layer. Monitoring systems need to assess the net difference in each pool for project and nonproject (or pre-project) areas over a period of time. By comparing these changes in the project area to changes in pools unaffected by project activities (i.e. comparison plots), the monitoring effort can assess the impact of the project on carbon storage. Detailed biomass measurement methods can be found in MacDicken (1996).

For each pool, measurements should start in both project and comparison areas before the project begins so as to confirm the similarity of the comparison area to the project area, and to provide a basis for determining changes in the amount and types of biomass on a particular site over time. Measurements should be made on an annual basis at the same time each year; monitoring frequency may need to be increased if there is a substantial amount of annual (as opposed to perennial) vegetation at the site (see Section 3.5). In addition to measurements, records should be kept on disturbances at the sites, whether man-made (e.g., thinnings) or natural (e.g., pest infestation).

One of the key monitoring and evaluation issues is determining which of the carbon pools are significant and which are likely to change. The significance of a carbon pool may be defined by its relative size and speed of change:

> "For example, in a forest preservation project, the carbon stored in trees may represent 70-80% of the total carbon stored on site, and consequently is a relatively significant pool. Leaf litter contains only 1% of the carbon contained in the trees and, therefore, does not represent a significant pool in terms of relative size. Changes in pools that are directly attributed to project activities should be the focus of the monitoring program, but changes in all pools need to be evaluated for their relative significance to the project's carbon balance." (EcoSecurities 1997)

Thus, it may be useful to rank the carbon pools according to their significance (relative size), vulnerability (rate of change), and direction of change (positive or negative). Pools that are relatively large and that are likely to change rapidly are very important to monitor. Pools that are relatively small and unlikely to change are not so important to monitor. A monitoring and evaluation program should adopt a conservative approach when deciding upon which pools to monitor and evaluate. Only pools that are monitored and evaluated should be considered in the calculation of GHG impacts. Some small pools may not justify the expense required to acquire reasonably reliable estimates of carbon contents (e.g., fine roots or fine litter); default values for carbon storage may be used in these cases (IPCC 1995; World Bank 1997b).

5.6.1. Above-ground woody biomass

Trees are usually measured standing, except at the time of thinning or felling when they can be measured on the ground. Volume is the most common measure taken and the three most frequently used parameters are stem diameter at breast height (DBH), basal area at breast height, and tree height. These parameters will give stem volume. If no allowances are made for branches and tops, then the above-ground volumes can be underestimated by a 15-50%; and if roots are not considered, then the estimated volume may only be 30-50% of actual volume (World Bank 1994a). For carbon sequestration, total above-ground volume is required and can be derived from a statistical analysis relating the measured total volume of felled trees to the parameters described above on a species-specific basis.[1] After measurements have been taken to estimate either volume or weight, these measurements must be converted to estimates of total standing stock, annual take-off and productivity. The productivity information can be taken from continuous monitoring of sample plots in the field, or from secondary sources.

5.6.2. Below-ground woody biomass

Roots store carbon and contribute to the build-up of organic soil carbon. It may be necessary to measure tree roots — either on the plots or on trees felled outside the project area, to obtain ratios between above- and below-ground woody biomass. These measurements should be compared to the rule of thumb that approximately one-third of the mass of a tree is below ground (World Bank 1994a).

5.6.3. Calculating carbon storage in woody biomass

Once stand or total tree volume or weight has been estimated, this measure must be converted into organic carbon weight. There is very little variation in chemical composition of all wood species and on an ash free, moisture free (bone dry) basis, approximately 50% of wood by weight is carbon, 6% is hydrogen, and 44% is oxygen (World Bank 1994a). Although the chemical composition of wood does not vary much, density and moisture content vary considerably by species (e.g., coniferous wood species are generally much less dense than hardwood species). Density can be determined by taking pieces of wood of known dimensions, weighing them, subtracting the weight of water, and dividing the volume into the

[1] Alternatively, volume tables from previous studies can be used if they exist and are sufficiently documented to support their application to the current project; however, felling trees provides more information than pre-existing volume tables. Biomass expansion factors are widely accepted, if properly used (see Brown et al. 1989).

bone dry weight. Moisture content can be measured by weighing the wood as received and reweighing it after it has been dried in an oven until its weight is constant. Alternatively, a moisture content meter can be used which will give a direct reading of moisture content.

5.6.4. Carbon storage in annual plants

Forestry residues can be used as renewable resources to substitute for fossil fuels. Samples need to be weighed and moisture contents need to be determined as for woody biomass. Unlike wood, there is a large variation in the ash content of different kinds of crop residues and, therefore, ash content needs to be determined in order to calculate its energy value at different moisture contents (e.g., by completely burning known bone dry weights of residues and weighing the remaining ashes afterwards). The carbon content (and energy value) of crop residues can be measured directly using a bomb calorimeter, but average values can be used as a good approximation: on an ash free, moisture free (bone dry) basis, 46% of crop residues by weight is carbon (World Bank 1994a).

5.6.5. Soil carbon

For most lands, soil (to a depth of 5 meters) is usually a greater store of carbon than is biomass tissue, with the most carbon found in forest soils, followed by grassland soils and arable agricultural soils (World Bank 1994a). Thus, the buildup of organic carbon in the soil needs to be measured throughout the project site, down to a depth of 5 meters, with emphasis on the first meter. Ideally, soil samples should be taken each year at permanent sample sites in different age and land use classes, and the buildup of soil carbon recorded yearly. Using a bomb calorimeter, the carbon content of the soil is calculated.

But soil carbon does not need to be measured as part of forestry mitigation projects, if no carbon credits are granted for changes in soil carbon associated with the project. The potentially high cost of measuring soil carbon may suggest that consideration of changes in soil carbon in many forestry mitigation projects is not economically feasible.

5.6.6. Forest products

The long-term effectiveness of carbon sequestration depends on the uses of the wood produced through project activities. The more durable the wood product, the greater the project's carbon storage effect in the medium and long term. However, carbon stored in wood is obviously not stored permanently; organic compounds usually decay and some will ultimately reappear as GHG emissions. A monitoring and evaluation system to measure post-harvest carbon storage, particularly for medium to highly durable products, could allow reporting of additional carbon and improve the economics of projects that seek to grow higher value timber (MacDicken 1997).

An account should be made of what happens to the wood once it is felled or trees and branches die. If dead wood is regularly collected, it should be measured and its use recorded. If it is used as firewood, it may result in lower GHG impacts than if it is left to decompose. When logs, pulpwood, cord wood and chips are taken to a factory, a record should be made of the fate of this wood: e.g., waste, pulp and board products, animal bedding, fuel within the factory, fuel by households, industry, etc. Similarly, the kinds and quantity of finished products should be recorded: e.g., furniture, recycled paper, substitute for fossil fuel.

Given the inherent difficulty in determining the exact fate of wood products after they leave the forest or project area, another approach is to determine the proportion of timber that is converted into different products, and use general default values to estimate their average lifetime and decay rates (EcoSecurities 1997).

5.7. Net Carbon Impacts and Comparison Plots

The basic principle behind the evaluation of carbon storage is the comparison between the amount of carbon storage achieved under the project with the amount that would have been achieved without the project; this requires monitoring the project area as well as nonproject comparison sites prior to project startup. One can have comparison plots within the project area or outside the project area to supplement the sites within the project area. To establish the internal validity of the evaluation results, the comparison plots must be similar enough to the project area so that they can serve as a proxy for the project area under the assumption that the project was not implemented. Similarity can be established on the basis of the key factors that determine biomass productivity: rainfall, temperature, insolation, soil characteristics, species and land management. Land management or use is the most difficult criterion to meet since they could diverge significantly between comparison site and project areas. By selecting comparison plots within the project area, these divergences can be eliminated or minimized. There is no general way to ensure that the comparison plots will remain valid throughout the life of the project; special care and monitoring are needed.

5.7.1. Sampling

Sampling allows overall project performance to be assessed based on the performance of a manageable number of plots. For large, heterogeneous areas, a multi-stage approach may be appropriate, in which each stratum is divided into primary sampling units which are then subsequently divided into secondary sampling units. The type and intensity of sampling depends on the variations within each stratum. Biomass sampling studies typically aim for estimates of biomass weight or volume accurately to within ± 15% with a relatively high confidence (e.g., 90 or 95%) (World Bank 1994a).

A universally accepted level of precision for estimates of carbon benefits does not currently exist. As a general rule, the cost of a monitoring program is negatively related to the precision of the estimate of the carbon benefit. To a certain extent, the market value of carbon sequestered in carbon offset projects will determine the level of precision that is cost-effective. Some experts suggest that a reasonable target for the precision of a project's carbon benefit is a standard error of 20-30% of the mean (EcoSecurities 1997). Another option would be to adjust the carbon claims by discounting the standard error of measurements. Finally, it is unlikely that a common level of precision will be used for each of the significant carbon pools and flows.

The use of permanent sample plots is generally regarded as a statistically superior means of evaluating changes in forest conditions (MacDicken 1996). Permanent plots allow reliable and efficient assessment of changes in carbon fixation over time, provided that the plots represent the larger area for which the estimates are intended. This means that the sample plots must be subject to the same management as the rest of the project area. The use of permanent plots also allows the inventory to continue reliably over more than one rotation. Finally, permanent plots permit efficient verification at relatively low cost, compared to those that use temporary plots or plotless methods: a verifying organization can find and measure permanent plots at random to verify, in quantitative terms, the design and implementation of a project's carbon monitoring plan. For nonproject sites (e.g., savannas that are regularly burned or agricultural lands subject to tillage), permanent sample plots may not be needed and plotless sampling methods can yield acceptable levels of precision at lower cost.

There are four options for sampling design: complete enumeration, simple random sampling, systematic sampling, and stratified random sampling. For carbon inventory, stratified random sampling is generally preferred, since this often yields more precise estimates for a fixed cost than the other options (MacDicken 1996). Stratified random sampling requires stratification, or dividing the population into nonoverlapping groups. Each stratum can be defined by vegetation type, soil type, or typography. For carbon inventory, strata may be most logically defined by estimated total carbon pool weight, which largely depends on above-ground biomass, which will then be the primary strata for sampling.

Useful tools for defining strata include satellite images, aerial photographs, and maps of vegetation, soils or topography. These should be combined with ground measurements for verifying remotely-sensed images. A geographic information system (GIS) can automatically determine stratum size and the size of exclusions or buffer zones.

MacDicken (1996) provides a spreadsheet for inventory decisions which calculates sample sizes using standard formulas based on measured variation for the carbon pool to be sampled. Two approaches are proposed: (1) sample plot allocation based on fixed precision levels; and (2) optimum allocation of plots among strata given fixed inventory costs.

5.8. Summary

The unique features and diversity of forestry projects, the monitoring domain and socioeconomic issues pertaining to forestry projects, and the variety of carbon pools that might be impacted by forestry projects makes the monitoring and evaluation of forestry projects very challenging. While forestry projects offer the potential for significant carbon sequestration, the verification of carbon credit claims will necessitate significant technical and financial resources. A variety of monitoring tools are available for forestry projects (e.g., remote sensing, inventory analysis, surveys, and research studies) for determing the amount of carbon sequestered by forestry projects, each having its own advantages and disadvantages (Table 10). One of the key decisions that will need to be made will be determining the optimal level of transaction costs for implementing these methodologies.

Table 10. Advantages and Disadvantages of Forestry Monitoring Methods

Methods	Advantages	Disadvantages
Modeling	Relatively quick and inexpensive. Most useful as a complement to other methods.	Relies on highly simplified assumptions. Need to be calibrated with onsite data.
Remote Sensing and Ground Truthing	Used primarily for temperate forests, and experience could be transferred to other forests. Useful for monitoring leakage.	Has not been used to measure carbon. Not used for tropical forests so far.
Inventory Analysis of Carbon Pools	Flexible in selection of methods and precision. Peer reviewed and field tested systems available. Using control plots, can calculate net carbon sequestration.	More expensive than other methods, except for research studies.
Research Studies	Detailed monitoring. Relatively accurate.	Typically, more expensive than other methods.
Surveys	Useful for determining what was actually implemented in project. Most useful as a complement to other methods.	Does not, by itself, calculate net carbon sequestration
Monitoring of Wood Production, Use and End Products	Useful for tracking fate of wood products. Most useful as a complement to other methods.	Does not, by itself, calculate net carbon sequestration